METHODS FOR DRYING GRAIN ON THE FARM

A paper presented in Chicago, Illinois, before the American Society of Agricultural Engineers technical meeting on November 29, 1938, by C. F. Kelly of the Bureau of Agricultural Engineering, U. S. Department of Agriculture.

The Department of Agriculture, through the Bureau of Agricultural Engineering in cooperation with other bureaus and with State experiment stations, has for the past three years been carrying on investigations in the major wheat growing areas to find what type of storage structures will best preserve and improve the quality of wheat stored on farms, and the grades of wheat that can be safely stored for long periods. Since the moisture content of the grain is one of the factors affecting its keeping quality, part of the investigations have been directed towards developing bins with natural or forced ventilation that will lower the moisture content of the stored grain enough to make it safe for long-time storage. The safe value moisture content has usually been considered to be around 14 to 14 1/2 per cent, depending on the class of wheat and geographical region, but there is reason to believe that these figures may be too high. This paper will consider only the drying factor, although recognizing that at a low temperature wheat of a high moisture content will store safely and that in some cases as much benefit may result from the dissipation of heat by a ventilation system as by the removal of moisture.

There are two general methods of drying grain in bins; namely, by forced ventilation using a power operated blower or fan, and by natural ventilation using pressure developed by the wind or by differences in density between warm and cool air. All methods depend for their success on the relative humidity and temperature of the air forced through the wheat, the temperature of the wheat, and the amount of air supplied. At any given air temperature and relative humidity, a variety or class of wheat will reach a definite moisture content. As the air passes through the wheat, it will take up moisture if its relative humidity is below the equilibrium point of the wheat moisture content. When the wheat is colder than the air, the relative humidity of the air will increase by having its temperature lowered upon contact with the cooler wheat, so that less drying will take place than the initial relative humidity of the air would indicate. On the other hand, if the air is colder than the wheat, the amount of drying which can be realized is greater than that indicated by the initial relative humidity. These temperature and relative humidity relations apply to both natural and forced ventilation systems. The condition and amount of air passing through the wheat and its distance of travel determine the rate of drying for wheat of any given moisture content. In order to have some basis upon which to design naturally ventilated bins, we made a series of tests to find the amount of air movement through various depths of wheat by air pressures comparable to those furnished by the wind if all of its velocity pressure were transformed into static pressure. Chart 1 (slide) gives the number of cubic feet of air per minute per square foot of area forced through one, two, four, and eight feet depths of wheat, by pressures up to .7

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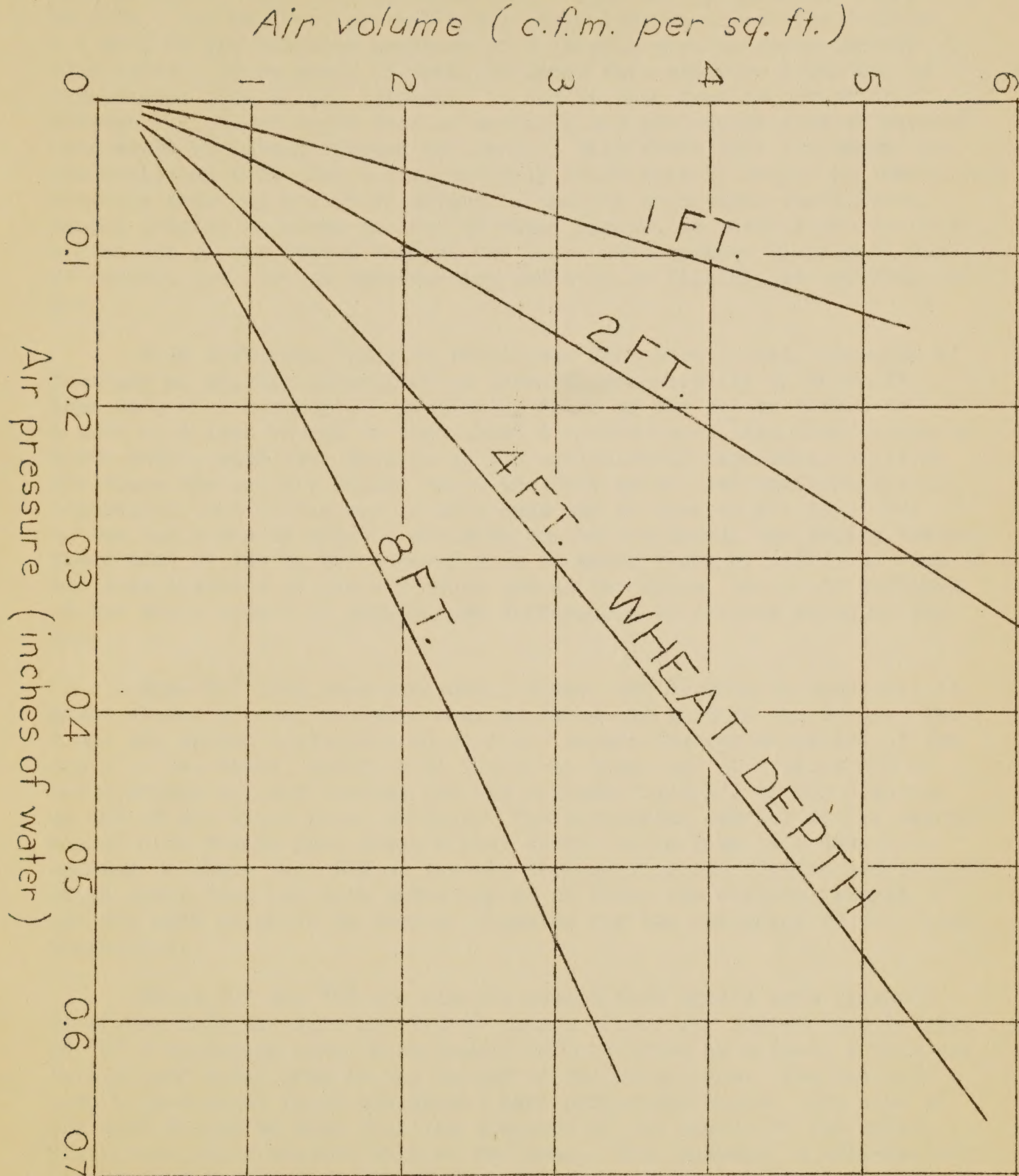


Air volume (c.f.m. per sq. ft.)
0
1
2
3
4
5
6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Air pressure (inches of water)
1 FT.
2 FT.
4 FT.
8 FT.
WHEAT DEPTH

Chart No. 1

inch of water. The wheat used was No. 5 hard red spring, test weight 52.7 lb., and moisture content 9.8%. By calculation from the formula $V = 4005 \sqrt{p}$ the velocity pressure of a 14 mile wind is approximately .1 inch water. If by means of cowls or hoods this pressure could all be transformed into static pressure, it can be seen from the chart that through a depth of eight feet of wheat, $\frac{3}{4}$ cfm per square foot of exposed area would be forced through the grain. This shows that the amount of air available from even a comparatively brisk wind is small and immediately suggests that any system of drying in the bin by natural ventilation should provide as large an area of wheat exposed to the air and as short a distance of air travel through the wheat as possible, keeping in mind, of course, low cost of construction and ease of filling and emptying the bin.

Many different types of ventilated bins were tested, but most of them may be roughly classified as shown diagramatically in Chart II. Type "A", with horizontal ventilating flues of fly screen tacked to 1 inch by 4 inch boards on edge about 4 inches apart, had been tested in North Dakota with some success by the agricultural experiment station. The flues are usually spaced about two feet apart both horizontally and vertically, and either one or both ends may be open to the air. Not having any means by which a pressure can be developed, any drying taking place must be due to the natural flow of water vapor by diffusion from the damp interior to the dry areas around the flues, or to air currents in the grain caused by temperature differences in various parts of the bin.

Type "B" also uses horizontal flues, but depends on some sort of power blower or wind pressure cowl to force air through the wheat. The flues are spaced vertically so that air passes through one-third of the depth of the wheat, entering at the floor level and at a point 2/3 of the distance up, and leaving the bin through flues 1/3 of the distance up and at the upper wheat surface. The horizontal spacing in the experimental bins varied from about 2 feet apart, as in Type "A", down to a spacing so close that 90% of the bin horizontal cross section was covered. In an eight foot bin with three layers of flues the vertical length of the air path is about 28 inches, allowing for the thickness of the flues themselves.

Types "C" and "D" are similar except that type C uses pressure developed from the wind and type D uses a blower for forced ventilation. In "C" a revolving cowl, kept headed into the wind by a vane, forces air into a perforated drum in the center of the wheat mass. The bin must have a perforated floor and should have perforated walls. The size of the drum should be such that the distance of air travel to the walls, floor, and upper surface will be the same. For instance, a 1000-bushel bin 14 feet in diameter with 8 foot walls, and with perforated walls and roof, should have a drum 7 feet in diameter and 1 foot thick. If this is placed in the center of the wheat mass, the length of the air path, neglecting diagonal distances, will be 42 inches to every surface.

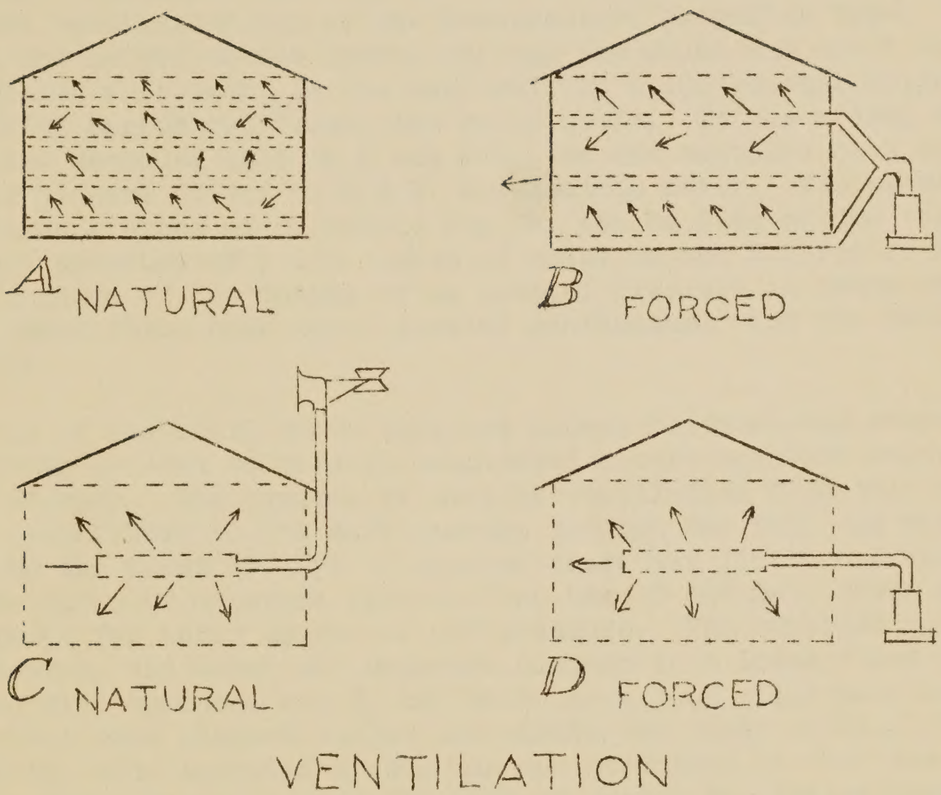


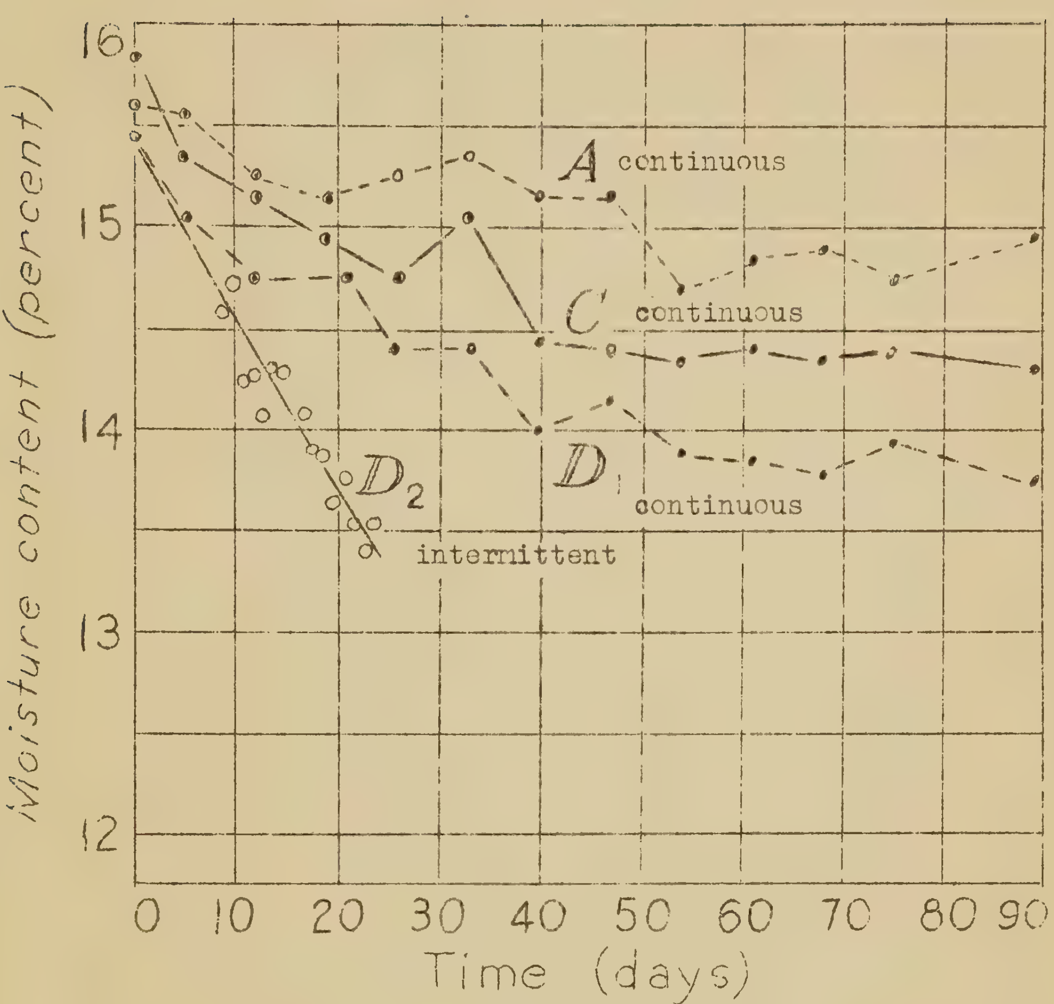
Chart No. 2

The drop in moisture content by days from four ventilated bins at Fargo, North Dakota, is shown by the curves in Chart No. 3. The letters signify the bin type as explained in Chart No. 2. The bins represented by curves A, C, and D-1 were filled from the same lot of wheat in 1937 and D-2 was filled in 1938. Bin "A" had eight horizontal flues arranged in three layers extending north and south through a double wall wooden bin of 485 bushel capacity. The average distance between flues was 32 inches. Bin "C" was the west half of a thousand bushel perforated floor and wall cylindrical metal bin and D-1 the east half of the same bin. C was equipped with a perforated drum connected to a pressure cowl above the bin, and D-1 with a similar drum connected to a 16-inch ventilating fan of the low-pressure propeller type. In both cases the length of air travel through the wheat was about 42 inches. Bin D-2, filled this year, is the west half of a 1000-bushel cylindrical metal bin with perforated floor, but solid walls. It has a drum the same size and shape as that in C and D-1, but was supplied with air by a silo-filler blower, driven by a 3 H. P. electric motor. The blower was operated on an average of an hour a day for the 24 days of the test, and developing a pressure of 1 1/4 inches of water in the central drum, as against a maximum of few tenths of an inch of pressure in drums of C and D-1. The other three bins were operated continuously for the period shown on the chart.

Study of the chart shows that not enough moisture was removed from bin A to bring it down to what is considered a safe moisture content for long-time storage. The removal of heat by ventilation from this bin undoubtedly contributed to its safe storage through the fall and winter periods. In the first 50 days of storage there was little difference between the rates of moisture removal from bins C and D-1, which were similar except for their source of air pressure. The ventilating fan in D-1, however, did lower the moisture content to a lower final level than in the wind operated bin C, and would have been still more effective if it had been stopped during the nights and rainy spells. In this connection the wind operated system has one advantage in that the wind velocity in North Dakota is usually highest during the driest parts of the day and lowest during the night, making a more or less automatic control on the ventilation. Bin D-2 of the chart, using a silo-filler blower, although operated only an hour a day during selected periods of low relative humidity, was very effective in removing moisture and because of this fact would probably be more successful in damp seasons when full advantage would have to be taken of very short dry periods.

When sold in April, 1938, the wheat in bin D-1 was in good condition. That in bins A, C, and D-2 is still in storage and in good condition.

It is interesting to note the varying drying results from one type of power ventilated bin in different geographical locations. This difference is shown in Chart No. 4. The locations indicated on the curves were at Hays, Kansas; Fargo, North Dakota; College Park, Maryland; and Urbana, Illinois; the letters referring to the ventilation type as illustrated in Chart No. 1. The North Dakota bin is the same as Bin D-2,



16
15
14
13
12
Moisture content (percent)
0
10
20
30
40
50
60
70
80
90
Time (days)
A continuous
C continuous
D_1 continuous
D_2
intermittent

Chart No. 3

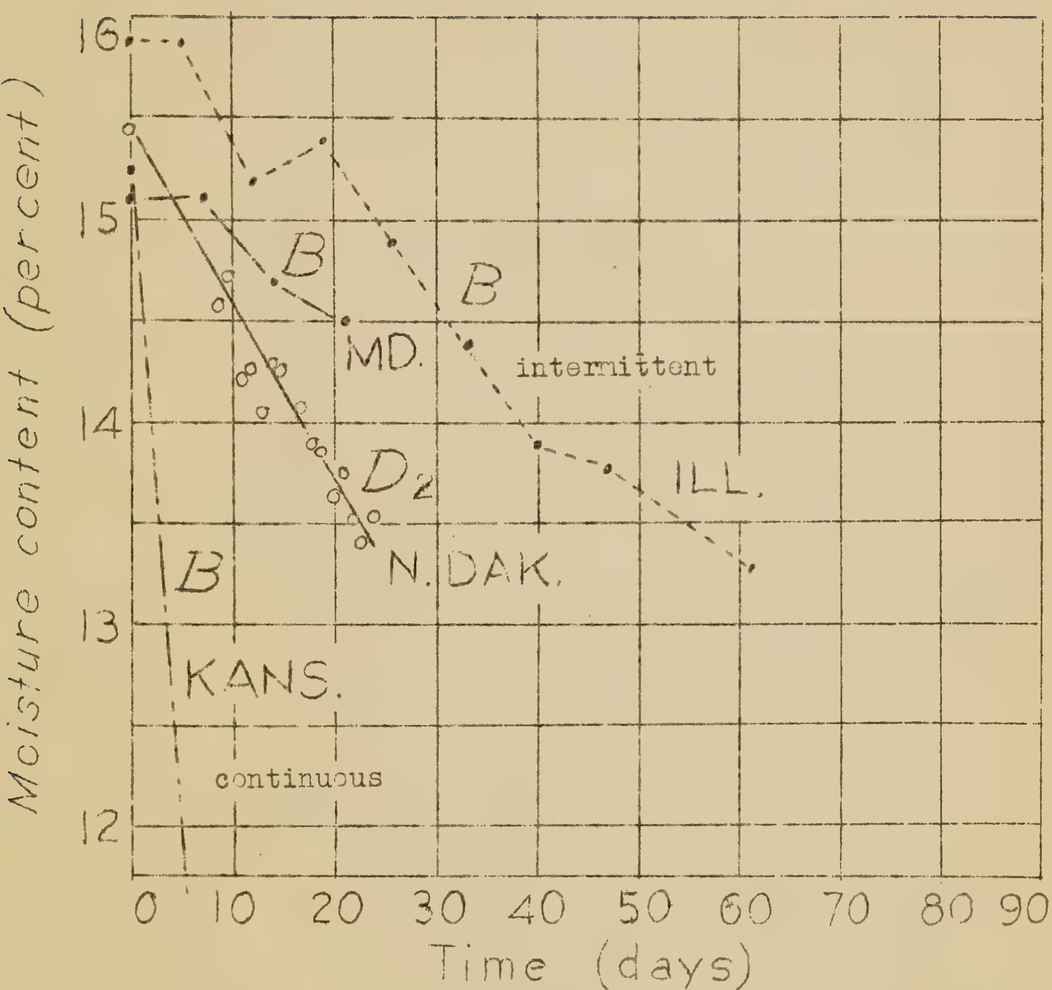

16
15
14
13
12
Moisture content (percent)
B
MD.
B
intermittent
D2
ILL.
N. DAK.
B
KANS.
continuous
0 10 20 30 40 50 60 70 80 90
Time (days)

Chart No. 4

referred to on Chart No. 3. The ventilation systems of the Illinois and Maryland bins were operated intermittently at times when the relative humidity was approximately 60%, the North Dakota bin an hour each day, and the Kansas bin continuously.

In Table I is given data showing the different conditions under which the bins operated, and the results.

Table I

	N. Dak.	Kansas	Md.	Ill.
Bin capacity (bushels)	485	500	274	300
App. Length of air path (inches)	42	24	22	20
Air (cfm./bu.)	1.53	1.08	1.43	1.77
Time blower operated (hours)	24	120	126.6	106.7
Ave. relative humidity (%)	45	38	52.5	68
Ave. air temperature (°F.)	82	84	80.5	78
Ave. wheat temperature (°F.)	75	82		86
Total moisture loss (%)	2.0	3.5	.6	2.6
Final moisture content (%)	13.5	11.75	14.5	13.3
Moisture loss (# per cu. ft. air)	.00054	.00027	.000033	.000137

The last figures show that the moisture removed per cu. ft. of air varied greatly, in North Dakota being 16 times, in Kansas 8 times, and in Illinois 4 times as great as in Maryland. The difference between North Dakota and Kansas results can be partly explained by the fact that intermittent drying allows diffusion of moisture to the surface to take place during the periods when the blower is not operated; and because much of the moisture in Kansas was removed at a grain moisture level below that in North Dakota.

The above examples of drying wheat in bins, typical of all the tests made in the investigation, indicate that in sections with climatic conditions similar to those of North Dakota and Kansas, in most years satisfactory results can be had with power ventilated bins, and that in some years the wheat can be kept in good condition in natural ventilated bins, although drying is very slow. Since dissipation of heat is an important factor in keeping the wheat, North Dakota probably has the advantage over Kansas because of its cooler fall temperature and because usually the storage season before cold weather sets in is shorter. Drying by natural ventilation in Illinois has been found to be unsatisfactory and forced ventilation fairly satisfactory in most years. However, in a wet year it is doubtful whether even forced ventilation could be depended on to give sufficient drying for safe storage. Our results indicate that in Maryland and similar areas both forced and natural ventilation are uneconomical and undependable as far as drying is concerned, although here again ventilation may furnish satisfactory storage for a time because of the dissipation of heat.

In areas such as Maryland and to a lesser extent Illinois, a method of drying by use of artificial heat appears to be necessary for dependable moisture removal. For this reason, in connection with the

storage experiments, some time has been spent in developing a portable small grain drying machine adaptable to use on the farm. Several points were recognized as desirable in a machine for this purpose, as follows:

1. Capacity of about 100 bushels per hour, great enough to take wheat directly from a combine or threshing machine.

2. Amount of moisture removed should be 2% or more, or enough to lower the wheat moisture content from 16% to less than 14%.

3. The germination and milling and baking qualities of the wheat should not be lowered.

4. The wheat, as it comes from the machine, should be at a temperature close to air temperature to allow it to go into storage immediately.

5. The cost of operation should be low.

6. The machine should be portable so that it can be moved from farm to farm.

7. It should be simple enough to enable a good blacksmith shop or small machine shop to make it at a reasonable cost.

The dryers in use commercially by seed houses and grain handling companies remove moisture effectively and in larger amounts than stated above, but because of the large quantity of grain in the machine while the drying process is carried on, are not easily moved from place to place. The most common types use hot air to carry the heat for evaporation to the grain and also to carry the moisture away. As the grain moves down between two parallel screens or other device, it is subjected to a stream of hot air. The first effect on the grain is to raise its temperature, during which time very little drying takes place; then comes a period of fast drying while the surface moisture is evaporated, and finally a longer period when the drying rate is relatively slow and depends largely on the rate of diffusion of moisture from the inner part of the kernel to its surface. After the desired moisture content is reached, another period is required to cool the grain down to a safe storage temperature by cold air.

In the grain dryer being developed by the Department of Agriculture the heat is applied directly to the wheat rather than to air, and air is used only as a carrier of moisture and not of heat. The direct application of heat to the grain shortens the heating time and probably also increases the rate of diffusion of moisture to the surface of the kernel where it is quickly evaporated. When the surface of the kernel is cooled by evaporation and cold air, the interior does not cool immediately and has a higher vapor pressure than the surface, causing the moisture to move outward at a rate in proportion to the difference in vapor pressure.

Two experimental machines have been built both following the general outline shown in Chart No. 5. As the process may be described as one of heating by conduction and cooling by convection, the machines are made up of two units, one in which the grain is heated, and the other in which it is cooled. The heating unit consists of a drum revolving in an oven heated by a coal burning furnace or oil burner. The cooler, where most of the drying takes place, consists of two parallel screens forming a duct for the grain, and a blower to force unheated air through the hot grain. In operation, the wet grain is placed in the feed hopper from which it flows by gravity into the revolving drum where it is heated to a temperature well above atmospheric. The heated grain passes into the top of the screened duct, which is kept full at all times, and travels downward to the outlet through a stream of cold air to which it gives up its heat and moisture.

In 1937 a small machine was constructed at Fargo, North Dakota, with a capacity of about 25 bushels per hour, using kerosene weed burners as a source of heat. The revolving drum, 13 inches in diameter and 5 feet, 10 inches long, was set at a slight angle with the horizontal to allow the grain to pass through it. Two longitudinal flanges on the inside of the drum served to lift and agitate the grain and make more even heating possible. The cooler consisted of two parallel screens of 14-mesh fly screen backed up by 1/2 inch mesh hardware cloth, placed 6 inches apart and having a cross sectional area of 9 square feet exposed to the air stream. The grain dropped by gravity from the heating drum into the top of the cooler, and was removed from the outlet by shovel at a rate such that the cooler was full at all times, so no air could by-pass or short circuit over the top of the grain. Electricity was used as a source of power for the blower and revolving drum.

A total of 2,822 bushels of new hard red spring wheat was dried at Fargo with this machine in a series of ten tests. The moisture removed varied from .77% at a rate of 48 bushels per hour to 2.32% at 19.7 bushels per hour. The cost for heat and power (kerosene at 10¢ per gallon and electricity at 5¢ per K.W.H.) varied between .46¢ and 1.34¢ per bushel for each per cent of moisture removed.

To compare the storage qualities of wheat dried by this method to that of naturally dried wheat, a 500-bushel bin was dried from 15.85% down to 14.15% by heating to 110° F. and cooling to 78°. The wheat, going through the machine at a 25 bu. per hour rate, was in the air blast approximately 8.5 minutes. The initial germination, before drying, was 94.2% and after drying 89.2%, a drop of 5%. The condition as indicated by odor and rancidity was the same both before and after drying. The odors and tastes given by milling and baking tests were natural after drying.

During the past winter a larger machine, mounted on the chassis of a Ford Model A car, was built near Washington for use at College Park, Maryland. This machine, shown on the slides, was very similar in principle to the one at Fargo just described. However, coal was used as a source of heat and the automobile gas engine as a source of power to drive the

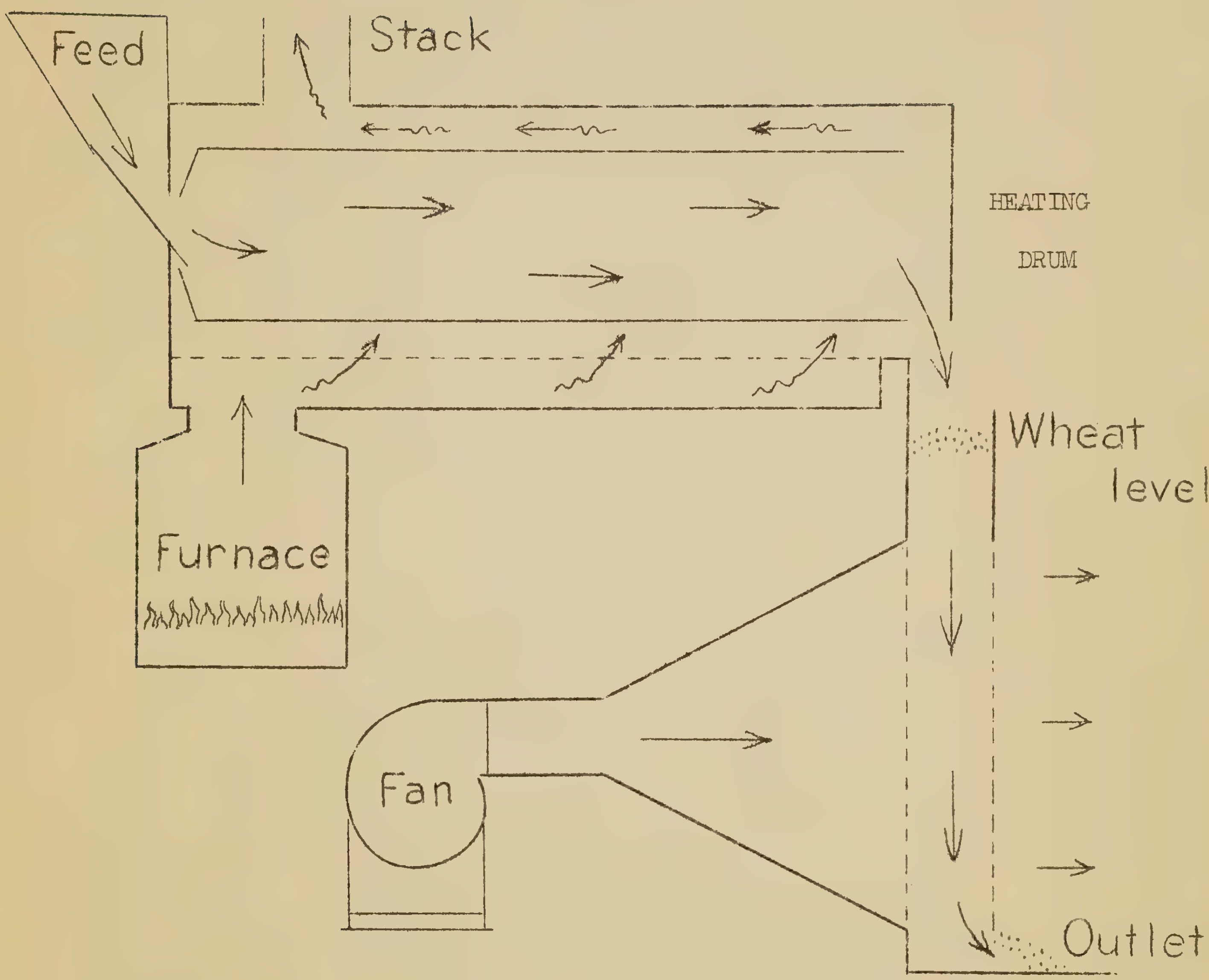


Chart No. 5

blower, drum, and elevator which lifted the hot wheat to the top of the cooler. The drum was 20 inches in diameter and 6 feet long, and the cooler, using the same type of screens as the Fargo machine, exposed 21 square feet of surface to the air blast. A blower capable of delivering 4000 cu. ft. of air per minute against a static pressure of 2 inches of water was used.

Several thousand bushels of soft red winter wheat, both new and re-wetted, have been put through this machine, with varying results. Early last summer, before the coal burning furnace heating system had been fully developed, 1200 bushels of new wheat were received and dried. Due to an overheated area in the back end of the heating drum, some of the wheat was scorched and had a fireburnt odor. This trouble has been remedied, but since that time we have had no new wheat on which to observe the effects of drying on germination and odor. The results from these preliminary tests are not indicative of the performance of the machine as it now stands, but are given because of the relation shown between temperature drop and moisture lost. The germination losses and fireburnt odor are undoubtedly due to the surface scorching of the kernels and not to the actual temperature reached.

The 1200 bushels were dried in three tests of 400 bushels each, the major data of which is given in Table II.

Table II

Test No.	1	2 (a)*	2 (b)*	3
Initial Moisture Content (%)	15.8	15.65	14.4	15.7
Final Moisture Content (%)	14.8	14.7	13.7	14.3
Temperature to which wheat was heated (°F.)	124.	126.	129.	138.
Final wheat temperature (°F.)	101.	101.	107.5	99.
Initial germination (%)	78.	78.	--	68
Final germination (%)	73.	--	60.5	32
Approximate rate of drying (bu./hr.)	100	100	100	55

*The 400 bushels in test No. 2 was run through the machine twice.

Although the wheat carried a fireburnt odor after drying, this did not carry through into the flour and bread.

The cost of operation of this machine, burning 30 pounds of coal per hour at $10 per ton and 1 1/2 gallons of gasoline at 16¢ per gallon, comes to 39¢ per hour or approximately .4¢ per bushel, regardless of the amount of moisture removed. A test of the oven efficiency indicated that approximately 25% of the heat value of the fuel was lost through the stack. Losses by radiation were not computed.

This method of drying has very definite limits beyond which it is impossible to go without reheating the grain. The line in Chart No. 6 has been drawn to indicate the limits of drying if all the heat stored in the

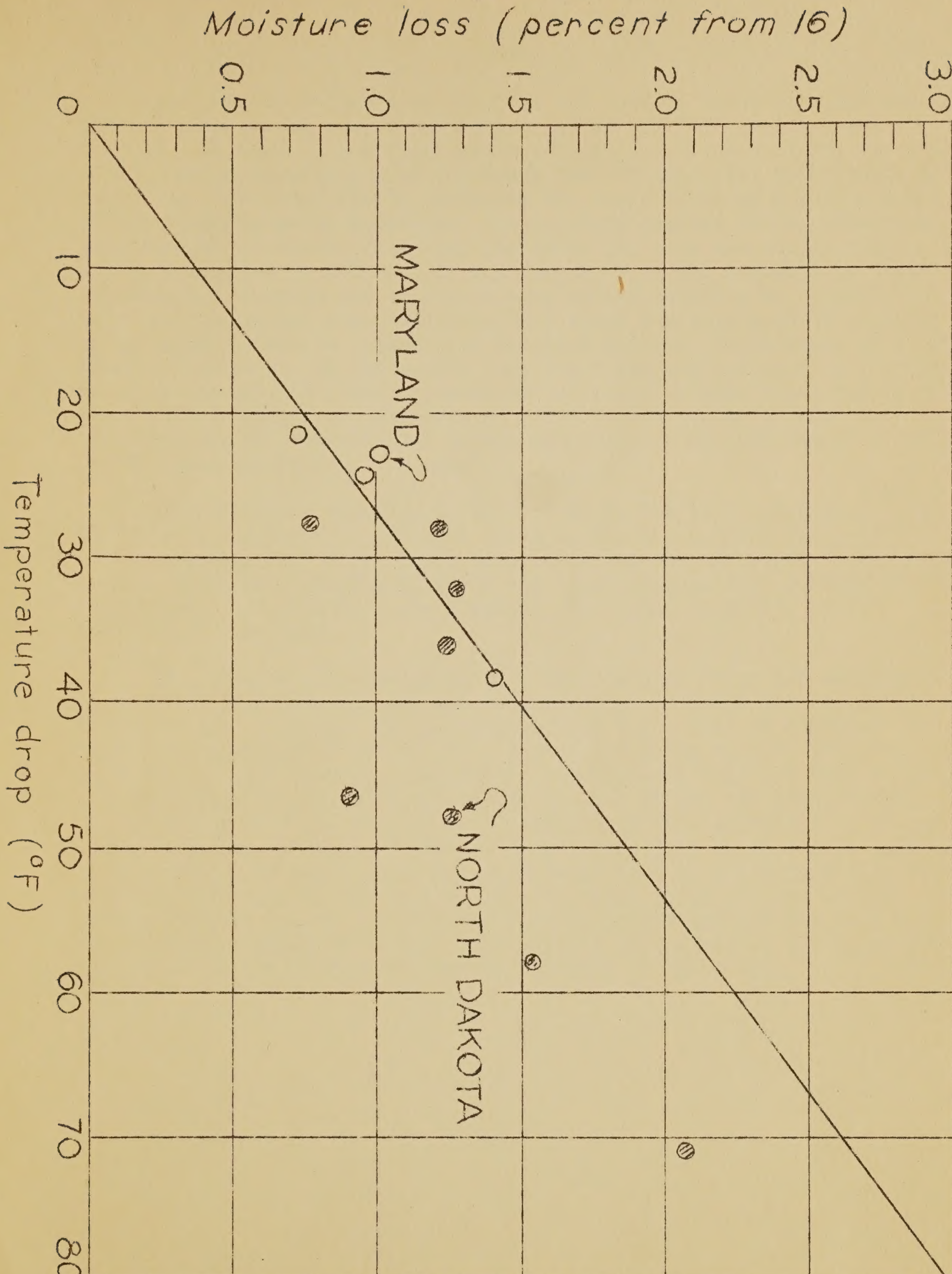

Moisture loss (percent from 16)
0
0.5
1.0
1.5
2.0
2.5
3.0
10
20
30
40
50
60
70
80
Temperature drop (°F)
MARYLAND
NORTH DAKOTA

Chart No. 6

wheat were used in evaporating moisture and none in increasing the sensible heat of the air. The curve was calculated by using a specific heat for wheat of .44 B.t.u.'s per pound and a latent heat of evaporation for water at the average temperature of the range through which the temperature drop was taken. The solid points represent the tests in North Dakota and the hollow points those in Maryland. The moisture content of the wheat was taken before it entered the drum, but since the only air circulation in the drum was that due to leakage, it was assumed that all drying took place in the cooler. However, the fact that some of the experimental points lie above the calculated line indicates that there was some loss of moisture by the wheat before it entered the screened cooler. These tests show that after the wheat was in the cooler very effective use was made of the heat. Readings taken of the air temperatures and relative humidities before and after it had passed through the grain show that actually a large part of the heat goes to evaporating moisture and only a small percentage to raising the sensible heat of the air.

Comparing the experiments made at North Dakota and Maryland, the former showed greater temperature drops in the wheat, with consequent greater drying, due to the lower temperature of the air blown through the wheat. Also the North Dakota wheat was light weight, with a larger number of kernels per bushel than the Maryland wheat, and therefore greater relative surface area.

The work so far carried on with this type of drier has encouraged us to think that it will meet the requirements mentioned before as desirable in a farm type machine. It is portable, has a low cost of construction and operation, capacity of 100 bu./hr., leaves the wheat in good condition for storage, and with careful attention to temperatures will not hurt the milling and baking qualities of the wheat, but may affect the germination. The amount of moisture removed being lower than that specified, a cooler having capacity to obtain a greater temperature drop in the grain appears to be needed. As the loss in moisture is limited by the temperature drop possible to obtain in the cooler, we have begun modifications of the machine to pass heated air from the furnace jacket through the drum during the heating process. This will give partial drying before the wheat enters the cooler in addition to the drying effected in the cooler.